# Much.Matter.in.Motion: Learning Science through Constructing Computational Models of Complex Systems (Short Paper)

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# חומר.רב.בתנועה: למידת מדעים על-ידי בניית מודלים חישוביים של מערכות מורכבות (מאמר קצר)

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### Abstract

The paper presents a study into students' learning of science through constructing computational models of complex systems with the new Much.Matter.in.Motion platform (MMM; Levy, Saba, et al., 2018). MMM's design highlights the epistemological structure of agent-based modelling: defining entities, their properties, actions and interactions with each other and with macro-level boundaries and fields. The study was conducted with six 7th-grade students and focused on conceptual learning of the topic of gases with the MMM environment; reasoning about complex systems; and on the use of the platform's affordances, using questionnaires, interviews, and screen-captures. Results show a significant rise in the overall scores; though mainly for the micro-level science concepts. Interviews' analysis showed greater changes in texture of the students' explanations: shifting from static to dynamic descriptions, compounding different steps, used more science concepts more correctly, and relating the micro-level rules to the macro-level patterns. Three of the modelling platform's affordances were used in activity's screen-capture movies: Macro-level objects are painted in, to remove the need of programming these objects. The use of numerical measurements at initial stages is minimized in service of supporting observation of the complex phenomena itself. Ease in changing the model, to encourage the shifts between successive models.

**Keywords:** Complex Systems, Computational Thinking, Modelling.

## Background

The paper presents a study into students' learning of science through constructing computational models of complex systems with an innovative platform, Much.Matter.in.Motion platform (hence, MMM; Levy, Saba, Hel-Or, Langhebeheim, Horn & Wilensky, 2018). It is part of a project, whose purpose is to develop a more coherent and consistent understanding of various science phenomena, based upon the complexity restructuration. Restructuration is a process by which representational structures undergo deep changes (Wilensky & Papert, 2010). This study focuses on agent-based modeling, a computation-based restructuration that transforms explanations of systemic phenomena to an emergent view.

Our theoretical perspectives combine a constructionist view of learning (Papert, 1988/93) and complexity approaches (Bar-Yam, 1997; Vicsek, 2002). Constructionism proponents learning through building personally-meaningful artifacts while sharing them with the community. Complex systems include many interacting entities, self-organizing in coherent global patterns (Bar-Yam, 2003). They are pervasive in our world; so that their understanding is crucial, as stated by the more recent USA science learning standards (NGSS, 2013).

### Learning through constructing models

Learning through constructing models is a less common practice in schools. Several reasons can be proposed for this state of affairs, such as the difficulty in learning and teaching programming, the added time needed for this learning and the question of whether students could understand and reason about complex phenomena and their representations. However, Constructionist research (Sherin, diSessa & Hammer, 1993; Wilensky, 1999a, 2001) have demonstrated richly expressive platforms for constructing models with computation. In our project, we use a visual block-based programming interface that makes it more accessible to younger students in more conventional settings (Weintrop & Wilensky, 2015).

### Learning science through a complexity perspective

Understanding complex systems is needed as people usually hold central control assumptions and confuse levels (Wilensky & Resnick, 1999). Several innovative learning environments have been designed to help people overcome these biases and understand complex systems, by constructing richly expressive computational models (Sherin et al., 1993; Wilensky, 1999b, 2001). This project supports students learning of complexity by constructing and exploring computer models of systems and studies their reasoning through both science and complexity perspectives.

### The Much.Matter.in.Motion Learning Environment

MMM's design highlights the epistemological structure of agent-based modelling (ABM; bottom-up modelling of many entities; Figure 1): defining groups of entities, their properties, actions and interactions with each other and with macro-level boundaries and fields. It was created with NetTango (Horn & Wilensky, 2014), a blocks-based interface to NetLogo (Wilensky, 1999a) to increase familiarity and accessibility. Distinct from modeling platforms that use a *computer science* framework, MMM emphasizes the *complexity-related constructs*. With respect to other modeling platforms highlighting ABM, it applies to a *wider range of phenomena*.

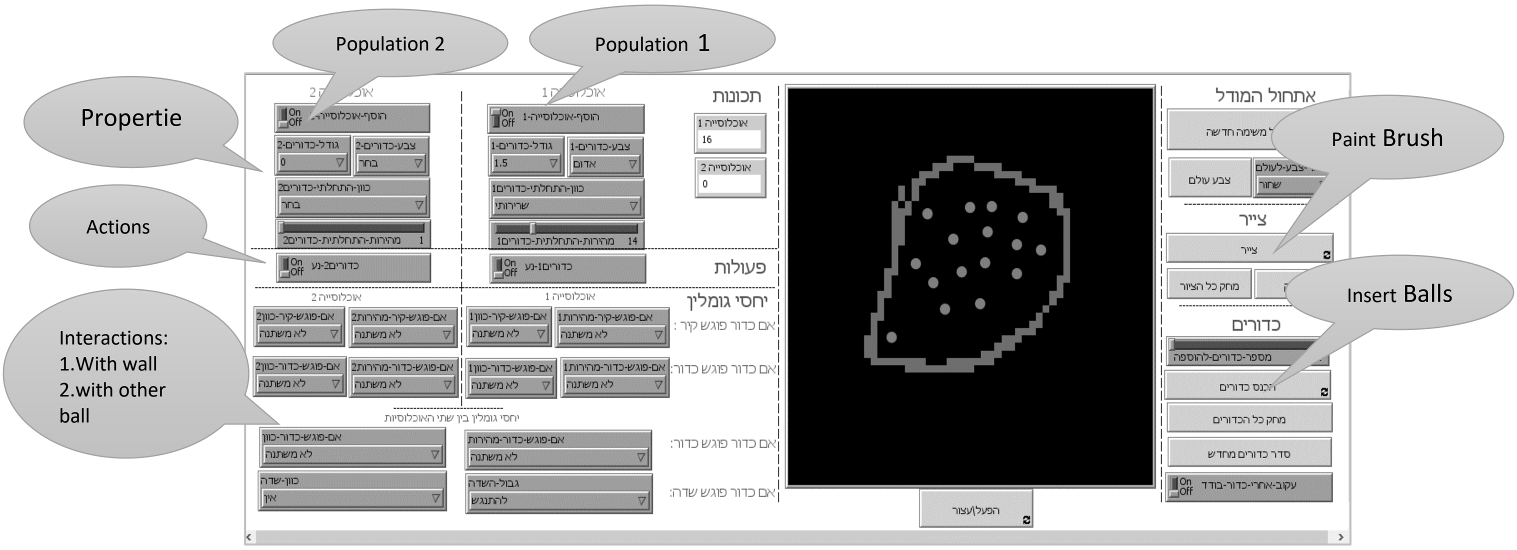


**Figure 1.** Design of the Much.Matter.in.Motion Interface

## Research questions

What learning takes place with the MMM environment?

How does the environment support conceptual learning of the topic of gases in chemistry, reasoning about complex systems and the development of modeling practices?

## Methods

The study was conducted with six 7$^{th}$-grade students in a school from the north of Israel. Students used MMM to learn the topic of gases in chemistry during three sessions, 1.5 hours each. They answered identical pre- and posttest previously-used questionnaires (Levy & Wilensky, 2009; Samon & Levy, 2017). Two students were interviewed before and after the learning process. The process of using MMM to construct models was screen-captured for two pairs of students.

The pretest and posttest questionnaire responses were coded as correct or incorrect and a total score was summed. Learning gains were computed as ((post-pre)/pre) computing learning gains relative to prior knowledge. A related-samples two-tailed Wilcoxon Signed Rank test was used to compare the differences between the pretest and posttest results. Interviews were transcribed and a thematic analysis was conducted. The screen-captures of the students' activities were analyzed with respect to the above-described design principles of MMM.

## Findings

Regarding conceptual learning, the questionnaires' analysis (Table 1) shows a significant rise in the overall scores from pretest to posttest from 65% to 78%. When considering the separate concepts, this rise is significant only for understanding Kinetic Molecular Theory, the microscopic rules underlying particles' behaviors.

**Table 1.** Pretest and Posttest Questionnaire Results (N=6).

| | | # Items | Pre-test M (%) | Post-test M (%) | Learning-Gain (%) | Wilcoxon p |
|---|---|---|---|---|---|---|
| Overall | Overall | 24 | 65 | 78 | 20 | 0.028* |
| Science concepts | Pressure | 5 | 70 | 77 | 10 | 0.180 |
| | Diffusion | 5 | 53 | 84 | 59 | 0.197 |
| | Density | 8 | 79 | 91 | 15 | 0.343 |
| | KMT | 10 | 60 | 80 | 33 | 0.039* |
| Systems Components | Micro | 6 | 50 | 76 | 52 | 0.074 |
| | Macro | 6 | 57 | 72 | 26 | 0.276 |
| | Micro-Macro | 12 | 67 | 86 | 28 | 0.102 |

* Sig. < 0.05

The interview questions were categorized by scientific phenomena and analyzed by science concepts and systems reasoning components, both deductively and inductively from the transcripts. Comparison of the interviews did not corroborate the results from the questionnaires. Results show that in the posttest, distinct from the questionnaire, the students used more science concepts more correctly, and increased in relating the micro-level rules to the macro-level patterns.

To explore how the MMM environment supports learning, one of the activity's screen-capture movies were analyzed for two pairs of students (Table 2). As this RQ seeks to understand the relationship between the environment's design and the students' learning, three design principles of the environment were focused upon.

Different from many modeling environments, in MMM, *macro-level objects, such as containers and pipes are painted in, to remove the need of programming these objects*. In these episodes, the students quickly drew and discarded several containers of different sizes and shapes to test out their ideas.

To focus on conceptual understanding, the use of numerical measurements at initial stages is minimized in service of supporting observation of the complex phenomena itself. Not having numbers did not hinder the students' articulation of the main scientific ideas, using qualitative relationships.

A third principle was *making changing the mode easy, to encourage the shifts between successive models*. The students created several versions of their model, demonstrating the modeling fluidity that MMM supports.

**Table 2.** Pretest and Posttest Interview Results

| | Pretest | Posttest | Comparison |
|---|---|---|---|
| **Inflating a balloon:** The interviewer provided the student with a drawing of a balloon and some coins that represent particles. | **Interviewer**: *I have an empty balloon, and now I'm blowing it up… how can you describe this in the drawing?* **N**: *Air goes in, no?* Interviewer: *How can you describe it in your drawing?* **N**: *Particles enter the balloon.* | **Interviewer**: *Now, I have an empty balloon and I'm about to introduce air into it.* **N**: (shows the balloon) *Is it empty?* Interviewer blows up the balloon and ties it. **Interviewer**: *What do you think happens when blowing up the balloon?* *N: You add more particles, and… the volume… will be bigger.* | The pretest answer expresses an understanding of particles moving through space, without noting the balloon's inflation The posttest answer considers particles entering the balloon as in the pretest, but then relates this event to a change at the macro-level, the increase in volume. |
| **Inserting the same amount of air into a big balloon and a small balloon:** The interviewer provided the student with a drawing of two balloons with different sizes and coins that represent particles. | E placed 11 coins inside each of the two balloons. First, they were bunched together; she then proceeded to space them out in the balloon, with larger gaps in the big balloon. **Interviewer**: *Can you explain your drawing?…* **E**: *The density of the air is greater, larger here in the small balloon, and smaller in the big balloon.* | E draws 15 particles inside each of the two balloons, with greater distance between them in the big balloon. **Interviewer**: *Can you explain your drawing?* **E**: *In the small balloon the pressure is higher because the particles bounce more with the walls of the balloon. And in the big balloon the pressure is lower because the particles bounce less with the edge with the balloon walls.* | In action, we see the student, in the pretest, dealing with inserting the particles in the balloon in two steps. The first step is entering the balloon as a clump; the second step is spreading them out evenly in the space. Density is a macro-level concept that is related to the micro-level distance between particles. While in the second phase she's focusing on creating distances between particles, they are named through the macro-level property. This answer shows thinking only at the micro-level, she used the term density as visualized result of inserting the same amount of particles inside two balloons that are different in sizes. While in the pretest, she had to deal with putting the particles in with two steps, in the posttest – perhaps because this is a drawing – she does it in one step. What makes this answer distinct is her discussion of collisions at the micro-level and pressure at the macro-level. This answer shows a shift towards deeper explanation by bridging the micro and macro levels. She succeeded in building a relationship between the amount of the particles, their collisions with the balloon walls at the micro-level, and its effect on pressure at the macro level. |

## Scholarly significance

A basic restructuration of systems in science enables its gradual adoption by modeling through a complexity perspective. The novelty in the design is having the epistemological structure lead the process of modeling, rather than the structure of computation. The study shows that students learned the micro-level chemistry concepts, and quickly reached competence in construction, shifting between models, and reflectively iterated and refined their model. This study is the first of several studies. It shows directions for improvement, such as a better articulation of the science concepts while they are learned, as well as supporting some of the working hypotheses regarding how the design would support learning.

## References


Bar-Yam, Y. (1997). *Dynamics of complex systems*. Reading: Addison-Wesley, The Advanced Book Program

Bar-Yam Y (2003). *Dynamics of complex systems*. Perseus Publishing, New York.

Levy, S.T., & Wilensky, U. (2009). Students' Learning with the Connected Chemistry (CC1) Curriculum: Navigating the Complexities of the Particulate World. *Journal of Science Education and Technology*, 18(3), 243–254.

Papert, S. (1988; 1993). *Mindstorms: Children, Computers and Powerful Ideas* (2nd edn). New York: Basic Books.

Samon, S., & Levy, S. T. (2017). Micro–macro compatibility: When does a complex systems approach strongly benefit science learning? *Science Education*, *101*(6), 985–1014.

Vicsek, T. (2002). Complexity: The bigger picture. *Nature*, *418*(6894), 131.

Weintrop, D., & Wilensky, U. (2015). To Block or not to Block, That is the Question: Students' Perceptions of Blocks-Based Programming. In: Proceeding IDC ' 15 Proceedings of the 14th International Conference on Interaction Design and Children, 199–208

Wilensky, U. (1999a). *NetLogo*. Center for Connected Learning and Computer-Based Modeling, Northwestern University. Evanston, IL. http://ccl.northwestern.edu/netlogo.

Wilensky, U. (1999b). GasLab: An extensible modeling toolkit for exploring micro- and macro-views of gases. In Feurzig, W., and Roberts, N. (Eds.), *Modeling and simulation in science and mathematics education*, Springer, New York, pp. 151–178.

Wilensky, U. (2001). Modeling nature's emergent patterns with multi-agent languages. In *Proceedings of EuroLogo* (pp. 1–6).

Wilensky, U., & Papert, S. (2010). Restructurations: Reformulations of knowledge disciplines through new representational forms. *Constructionism*.

Wilensky, U., & Resnick, M. (1999). Thinking in levels: A dynamic systems perspective to making sense of the world. *Journal of Science Education and Technology*, 8(1), 3–19.